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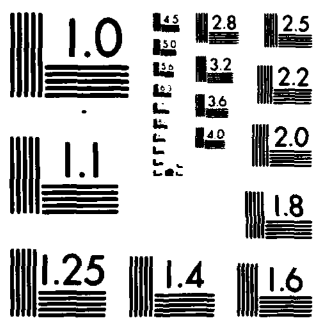

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SACLANT ASW RESEARCH CENTRE MEMORANDUM

A METHOD FOR COMPARING DIGITAL XBT COMPRESSION TECHNIQUES

by

RICHARD F. J. WINTERBURN

15 DECEMBER 1979

NORTH ATLANTIC TREATY ORGANIZATION

LA SPEZIA, ITALY

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A METHOD FOR COMPARING DIGITAL XBT COMPRESSION TECHNIQUES

by

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Richard F.J. Winterburn

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This memorandum has been prepared within the SACLANTCEN Underwater Research Division as part of Project 01.

G.C. VETTORI
Division Chief

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A METHOD FOR COMPARING DIGITAL XBT COMPRESSION TECHNIQUES

by

Richard F.J. Winterburn

ABSTRACT

expendable bathythermograph

The compression of digitally recorded (XBT) profile data is a necessary pre-requisite to their use in many applications. A method of comparing different compression techniques using a UNIVAC 1106 computer is presented. By applying three such techniques to over 200 XBT profiles recorded during various cruises of the R.V. MARIA PAOLINA G., a comparison of the results has identified the optimum method, which has now been adopted for XBT data compression at SACLANTCEN.

INTRODUCTION

With the acquisition of digital XBT* data into the UNIVAC 1106 System [1] and the subsequent development of a comprehensive software package to edit the profiles interactively [2], it has become necessary to examine various means of compressing the data to a more manageable size. This is particularly necessary when it is required to insert the XBT profile into the SMODS** Data Base [3] (which would allow use of the available display/analysis software [4]) since the maximum allowable length is 125 D/T (depth/temperature) pairs.

This memorandum describes a software comparator designed to allow the effect of any filter/compression algorithm on an XBT profile to be compared with that of another. It also presents results of a comparison of three such techniques applied to the XBT data of two SACLANTCEN cruises in 1977/78 [5,6].

1 METHOD

Figure 1 gives a simplified flow-chart of the steps of the comparison program. In essence the program inputs a number of XBT profiles, subjects each of them to a number of compression techniques, and stores the results for a later comparison of the overall effect of each technique. As can be seen, the program contains two nested loops; LOOP1 is repeated for each filter and LOOP2 is repeated for each profile. These iterations are followed by the "best-effect" statistical computations. In this way the I/O (input/output), filtering, and comparison sections are completely independent of one another, allowing easy modification of the software to

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**Expendable Bathythermograph*

***SACLANTCEN Military Oceanography Data Support*

include new filters, compression techniques, output displays, etc. as they are required.

At step B there is a choice of three techniques of compression, each of which is described in detail in Ch. 2. The output from this step may be either a filtered profile or a compressed profile. If it is the former then it is linearly interpolated onto a fixed increment depth scale as a means of compression. For the present tests this has been a 5 m scale within the depth limits of the filtered profile; if however it is the latter, no such interpolation is carried out.

The comparison itself is made by first linearly interpolating each compressed profile to the same depths as the original profile (step C) and then conducting a statistical analysis of the temperature variability at these depths between each original value and its compressed profile value; this is described in detail, with examples in Ch. 3.

2 THE COMPRESSORS

Three compression techniques have been compared, viz:

- Method 1 : LANCZOS filter and interpolation.
- Method 2 : Significant point selection.
- Method 3 : Smoothing polynomial and interpolation.

Of these, Methods 1 and 3 are digital filters followed by discrete sampling, whereas Method 2 is an objective selection technique yielding directly a compressed profile. Each of these will now be described in detail.

2.1 Lanczos Filter

The XBT data is originally digitized at a time interval equivalent to a depth increment of 0.6 m and, after filtering, the smoothed data will be sampled at 5 m increments. It follows therefore that for any filter to act on this data, the nyquist frequency, which is expressed as the reciprocal of twice the time interval between successive observations of an equally-spaced time series, is given by

$$f_{nyquist} = f_s = \frac{1}{2*0.6} = 0.833 \text{ cycles/m}$$

(i.e. 1 nyquist = 0.833 cycles/min)

and

$$f_{cutoff} = fc = \frac{1}{2*5} \text{ cycles/m}$$

$$= 0.12 \text{ nyquist}$$

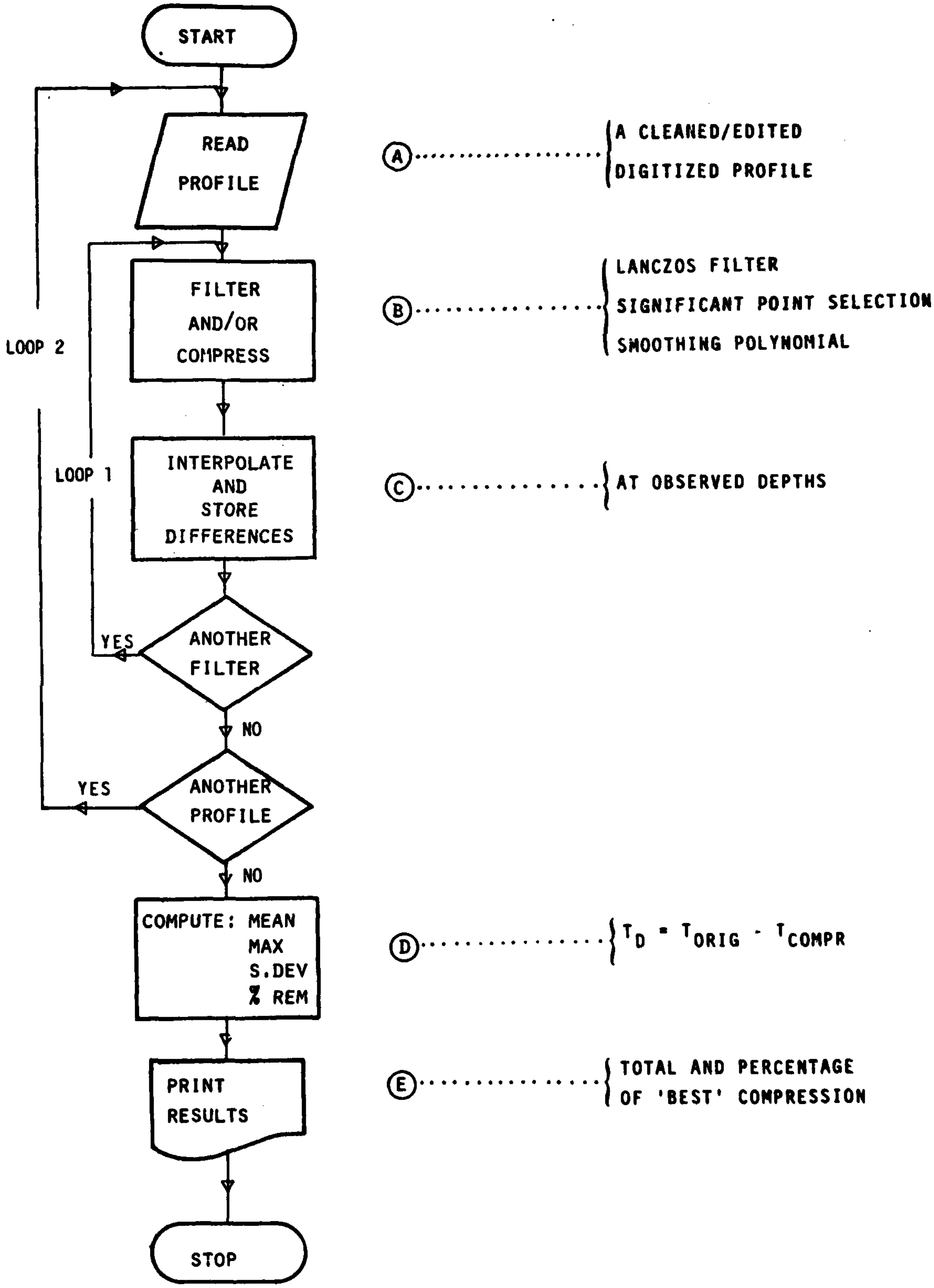

FIG. 1 GENERAL FLOW-CHART

The Lanczos filter [7,8,9,10] is a low-pass gaussian filter; as its weights sum to unity it ensures that there will be no change in either the phase or the mean value of the series. However, it is a penalty of such a filter that the first and last m constituents (m = the number of side weights) of the series must be discarded.

In the case of XBT data, it has been recognized [11] that the first 4 m of the profile are normally unreliable due to problems of the response of the sensor to the air/sea temperature difference at launch time. This corresponds to the first six scans of the digitization and therefore, in order to retain as much of the profile as possible, the filter characteristics have been computed over 13 weights, i.e. a central principal weight and six matched pairs of side weights. A compromise must always be made here, as the number of weights directly influences the slope of the gain of the filter; if the number of weights is increased, although the slope of the gain would increase, the number of data points at the limits of the series to be discarded would also increase.

The weights of the Lanczos filter have been computed by [9]:

$$S_j = V_j * \frac{2m + 1}{V_0 + 2\,\Sigma_{k=1}^{m} V_k} \qquad j = 0,1,\ldots 6$$

where j = the weight identifier

m = the number of side terms

$$V_j = \frac{\sin(\pi j/m) * \sin(\pi j\, f_c)}{j^2 \pi^2\, fc/m} \quad (f_c \text{ in nyquists})$$

which, substituting

$$f_c = 0.12$$
$$m = 6,$$

gives

$$V_j = \frac{\sin(0.524j) * \sin(0.377j)}{0.2j^2} \qquad j = 0.1,\ldots 6$$

from which the central and right-hand side weights have been computed as shown in Table 1, and, using the computer program of Pesaresi [10], the amplitude response as a function of frequency has been plotted (Fig. 2).

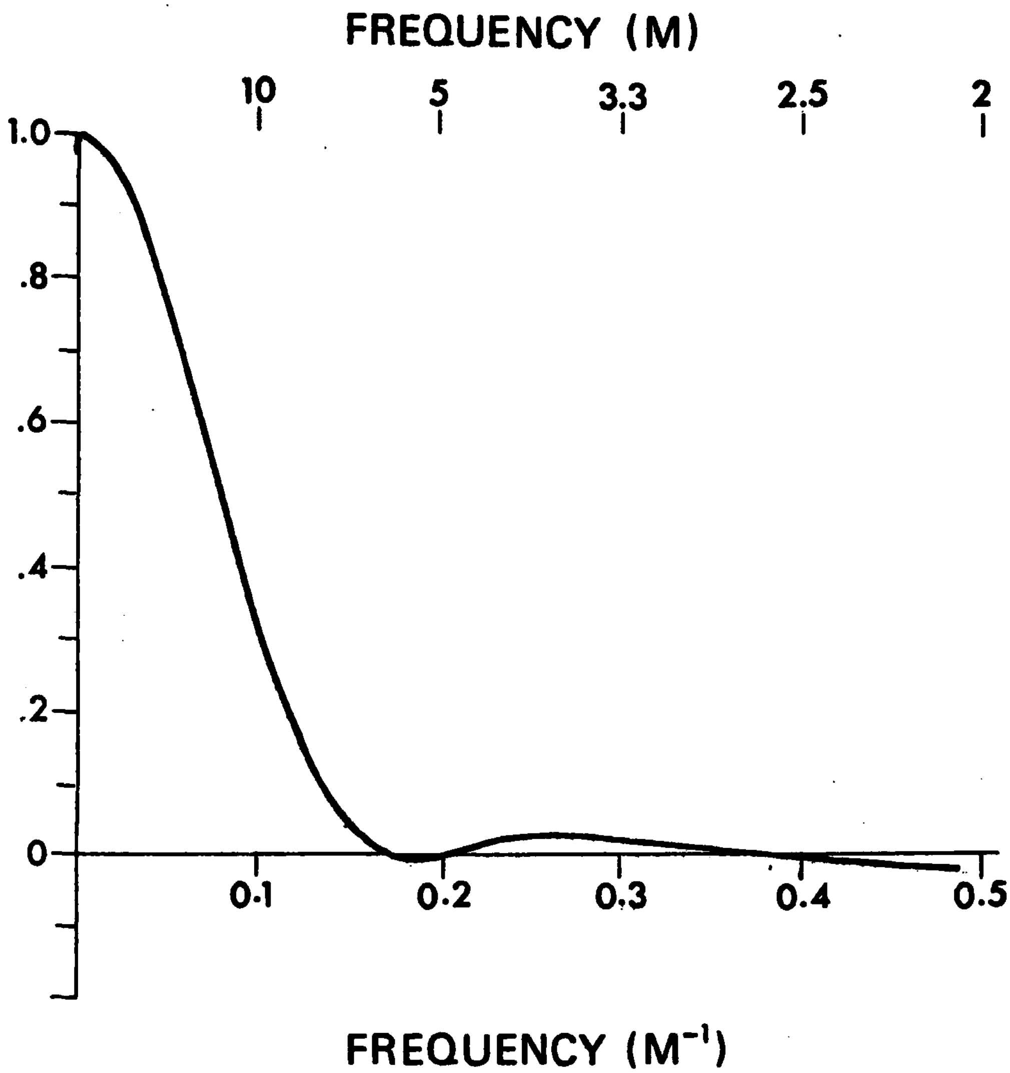

FIG. 2 AMPLITUDE RESPONSE AS A FUNCTION OF FREQUENCY OF THE LANCZOS FILTER

TABLE 1

CENTRAL AND RIGHT HAND SIDE WEIGHTS OF APPLIED LANCZOS FILTER

j	S_j
0	0.1676
1	0.1543
2	0.1165
3	0.0841
4	0.0453
5	0.0160
6	0.0000

Therefore, with this filter, the first and last 6 points (i.e. 3.6 m) of the profile are discarded; the resultant profile interpolated at 5 m depth increments, yields a compression to approximately 12% of the original.

2.2 Significant Point Selection

This is an objective selection technique that examines each point on the trace and decides, within certain criteria, if the point may be classified as redundant. This is carried out as follows. The first point on the profile is always accepted, then for each subsequent point (see Fig. 3), given that A is the last point to have been retained and that points B, C, and D have been classified as redundant, the problem is to determine if point E should be retained. The two parameters chosen to control this decision are:

(a) the gradient change at the point

(b) the deviation from the original trace of the straight-line segment created by discarding the point (α on Fig. 3).

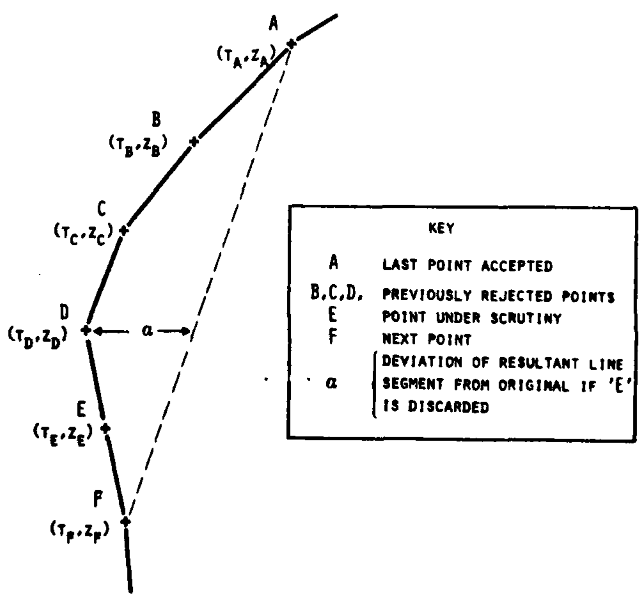

FIG. 3 SIGNIFICANT POINT SELECTION CRITERIA

The user of the routine has to input a minimum allowable value (parameter D2DIV) that the change in gradient must exceed to classify the point as a significant point. If this occurs, then the point is retained. However, in the case of a curve where the gradient change does not exceed this value (e.g. Fig. 3), before the point is discarded the second criteria is used. This checks if the deviation of the resultant line segment (α) is greater than a user-defined limit (parameter DELTAT), and the point is discarded only if this limit is not exceeded.

This criteria of deviation from the original record is an internationally-accepted standard; the IOC manual on international oceanographic data exchange [12] states that for XBT data

> "...flexure points determined in such a way that linear interpolations fall within ± 0.2°C of the original record."

Thus in Fig. 3, the point under consideration, E, will be discarded only if

$$\frac{t_E - t_D}{Z_E - Z_D} - \frac{t_F - t_E}{Z_F - Z_E} < \text{D2DIV}$$

and

$$\alpha < \text{DELTAT}.$$

This algorithm has been tested on over 200 XBT profiles, using a permutation of fiftenn combinations of D2DIV and DELTAT.

The results of using D2DIV incremented by 0.1 from 0.1 to 0.3, and D2DIV incremented by 0.010 from 0.005 to 0.045, are shown in Table 2, which for each combination of D2DIV and DELTAT gives the standard deviation of the error, the maximum error, and the mean percentage of points remaining after the compression has been carried out. From these results, the combination of D2DIV = 0.2 and DELTAT = 0.035°C (outlined in heavy black) has been selected as the most effective in compressing the profile to less than 125 data points (a SMODS data base requirement [3]) and yet having a maximum error close to the absolute accuracy of the instrument. Figure 4 shows the effect of increasing the value of DELTAT while compressing the same original profile, the number at the bottom of each profile being the number of constituent data points after each compression.

TABLE 2 SIGNIFICANT POINT METHOD TEST RESULTS

	STANDARD DEVIATION			PERCENT REMAINING			MAXIMUM ERROR		
DELTAT \ D2 DIV	0.1	0.2	0.3	0.1	0.2	0.3	0.1	0.2	0.3
0.005	0.000	0.009	0.009	31.59	35.98	35.92	0.05	0.12	0.10
0.015	0.000	0.009	0.009	31.58	35.76	35.70	0.05	0.12	0.10
0.025	0.001	0.010	0.010	31.42	33.00	32.83	0.05	0.12	0.10
0.035	0.001	0.022	0.022	31.37	14.78	14.57	0.06	0.17	0.14
0.045	0.001	0.023	0.023	31.37	13.30	13.02	0.08	0.17	0.14

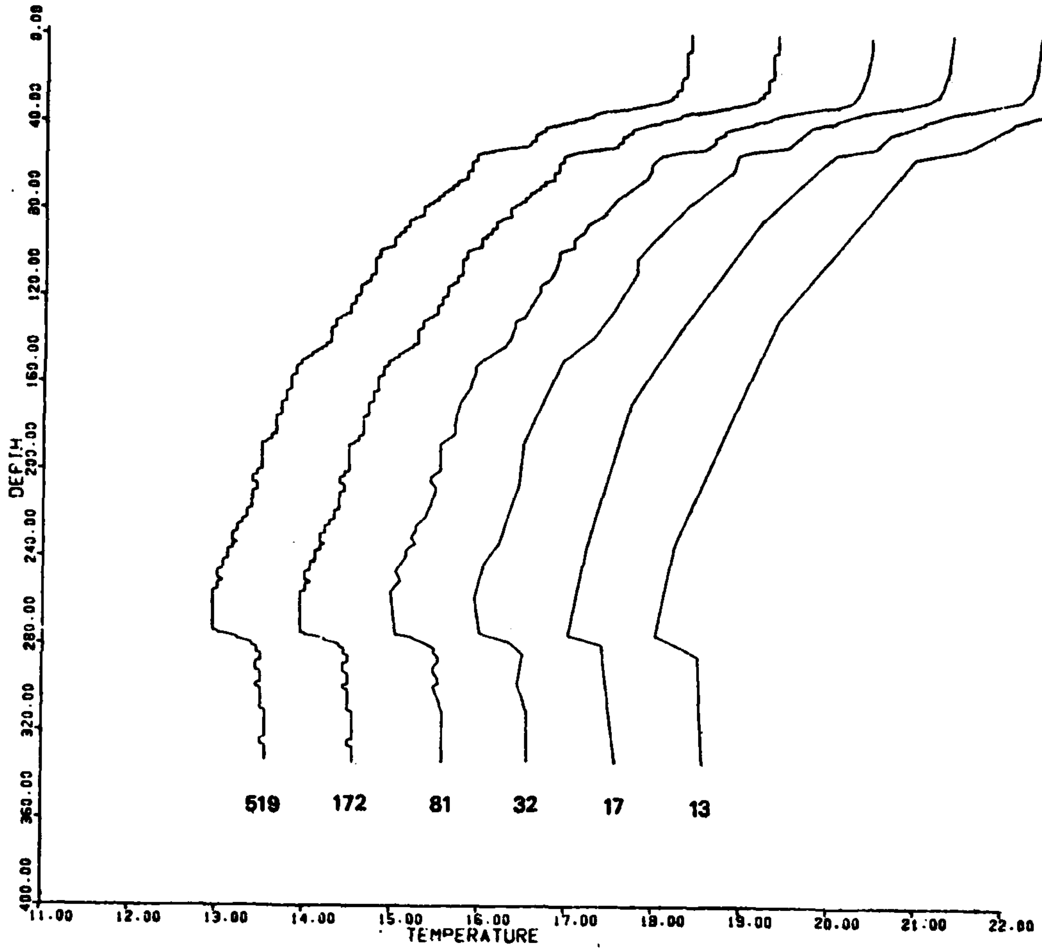

FIG. 4 SIGNIFICANT POINT SELECTION
Effect of increasing value of parameter DELTAT

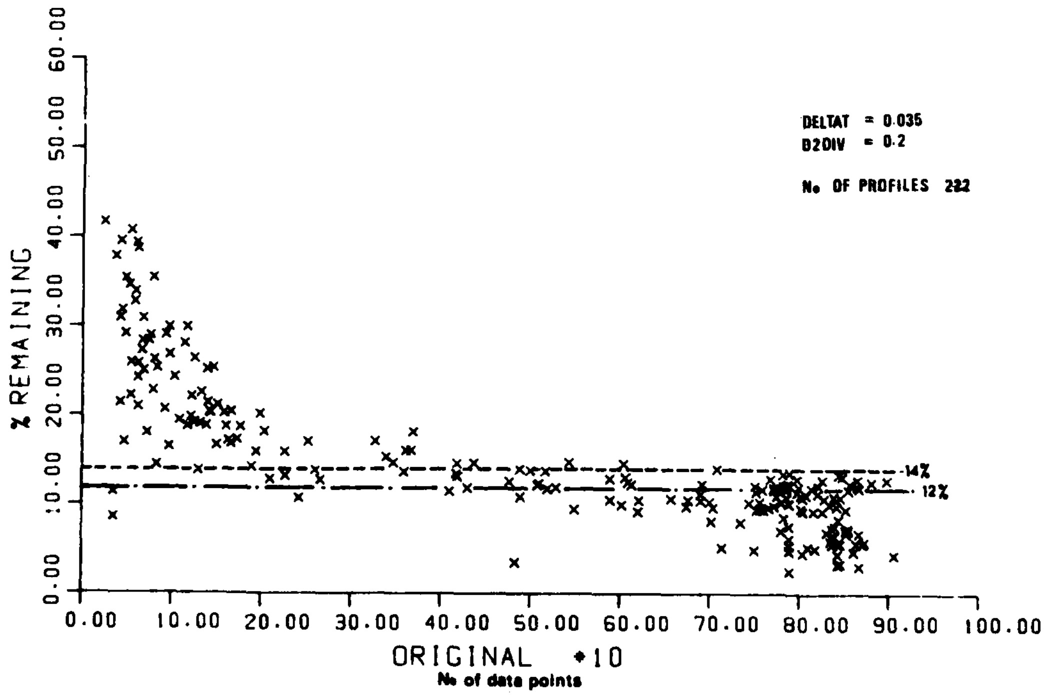

FIG. 5 PERCENTAGE OF POINTS REMAINING AFTER COMPRESSION, AS A FUNCTION OF ORIGINAL NUMBER OF POINTS

The rate of compression with this method varies with the complexity of the profile but in general approximates 14% of the original. This percentage reduction increases with the number of data points, as a result of the simplified nature of the temperature profile with an increase in depth, requiring fewer data points to be retained. This is clearly shown on Fig. 5 where the percentage of points remaining is plotted as a function of the number of original points for 222 profiles.

The number of points retained by fixed-level interpolation is of course directly related to the sampling frequency i.e. as is stated in Sect. 2.1, if a sampling rate of 5 m is required, the percentage reduction is 12%. This varies slightly, as there may be additional data points above and below the 5 m start and finish levels. This 12% reduction level is shown on Fig. 5 together with the mean value of the significant point reduction i.e. 14.78%.

2.3 Smoothing Polynomial

This is a direct application of the UNIVAC library routine MOVAVG [13], which fits a second order polynomial over a user-defined point extent.

For the purposes of this comparison, a 6-point extent was chosen (i.e. the smoothing formula goes from i-6 to i+6 for the ith element of the profile) to maintain compatibility with that used in Method 1, and the first and last six points discarded after the smoothing. Thus, after the 5 m interpolation is completed, a compression to approximately 12% is also achieved.

3 THE COMPARISON

The program, having filtered and/or compressed a profile to less than 125 points, carries out a linear interpolation at the same depths as the original trace, i.e. at approximately 0.6 m depth increments. From this the value

$$T_D = T_{ORIG} - T_{FILT}$$

is computed at each depth, and the mean, maximum, and standard deviation of T_D for each trace with each method is stored, together with the percentage number of points of the original profile remaining. Table 3 is an example of the computer report at this stage and shows these results for each method [Lanczos, Significant-Point (SIGNIF), and polynomial (POLY)], using individual BT profiles identified by a BT number (BTNO) and giving their original number of points (NPT).

When the compression of all the profiles is complete, a comparison is carried out to identify the most successful method in terms of least value of the mean, the maximum standard deviation, and the percentage of points remaining. This is output for all profiles (Table 4 is an example) for

TABLE 3 INDIVIDUAL STATISTICAL TEST RESULTS EXAMPLE

		LANCZOS				SIGNIF.				SM. POLY			
*TBD	NPT	MEAN	MAX	SIG	REM	MEAN	MAX	SIG	REM	MEAN	MAX	SIG	REM
2	35	-.0057	.0293	.0125	6.51	-.0160	.0451	.0162	8.57	-.0017	.0396	.0131	10.29
3	35	-.0019	.0296	.0129	8.61	-.0615	.0026	.0152	11.41	-.0021	.0465	.0140	10.29
4	52	.0126	.0703	.0326	9.63	.0682	.0921	.0161	34.22	.0050	.0735	.0235	13.06
5	47	.0013	.0559	.0230	11.34	.0021	.0645	.0227	12.09	-.0030	.0711	.0205	13.00
6	125	-.0317	.1761	.0501	12.00	-.0006	.0660	.0197	26.40	-.0019	.1037	.0027	12.00
7	163	-.0043	.1279	.0367	11.04	.0011	.0752	.0305	13.18	.0014	.1015	.0339	12.00
8	437	-.0004	.1313	.0241	12.36	.0020	.0621	.0199	14.65	-.0009	.0126	.0258	12.61
9	621	-.0011	.2225	.0266	12.90	.0011	.0729	.0231	10.47	-.0000	.2693	.0209	12.72
11	867	-.0000	.1521	.0271	12.34	-.0011	.5349	.0350	11.68	-.0002	.1021	.0260	12.57
12	768	-.0002	.1784	.0296	12.37	-.0012	.5355	.0348	12.29	-.0001	.1436	.0241	12.63
14	842	-.0002	.0846	.0206	12.35	.0040	.0658	.0227	10.57	-.0002	.3303	.0156	12.59
15	842	.0300	.1578	.0236	12.35	.0051	.5045	.0233	9.06	-.0000	.0303	.0188	12.59

TABLE 4 INDIVIDUAL 'BEST EFFECT' SELECTION RESULTS

	MEAN	MAX	S. DEV	REM
INDIVIDUAL XBT	3	2	3	2
	3	2	3	2
	1	1	1	2
	3	2	3	2
	1	2	3	2
	3	2	3	2
	1	1	3	2
	1	2	2	1
	1	2	2	1
	3	2	2	1

each method as a matrix on which the numbers signify the three methods:

1 Lanczos filter
2 Significant point selection,
3 Polynomial fitting.

These results are summed for each statistical test and the results output both as a total for each method and as a percentage of the total number of profiles under examination.

The results of the individual filters are then examined and average values of the mean, the standard deviation, and the percentage remaining are computed.

4 APPLICATION

In 1977/78 the SACLANTCEN Oceanographic group carried out two prolonged cruises in the Gulf of Cadiz [5] and Alboran Sea [6], during which a total of 222 XBT measurements were made using SACLANTCEN's on-board, on-line Oceanographic Data Acquisition System. These data have subsequently been transferred to the SACLANTCEN UNIVAC 1106 computer system [1] and cleaned and edited by an in-house-developed interactive editing package [2]. Finally, these data needed to be inserted into the SMODS data base [3] and for this reason their compression was essential.

These data could therefore be used to test the various compressions now available, as they include both deep (> 500 m) and shallow (< 500 m) casts with complex water columns (e.g. Atlantic/Mediterranean water masses).

The comparator has been exercised on these data and the most effective method identified. Table 5 gives the results of the test for "best effect" (as explained in Ch. 3) expressed in totals for each method under each test. These totals are also shown in Table 6 where they are expressed as percentiles of 222.

From these it is clear that in terms of least maximum error and standard deviation of the error, Method 2, the significant point selection, is the most effective. Although both the Lanczos filter and the significant point methods are equally effective at reducing the traces to the least number of points, the significant point method brings the profiles within the SMODS data base limit of 125 data points and is therefore acceptable.

Table 7, which gives the average values over the 222 profiles of the error parameters for each method, shows that the average maximum error of $0.0735^{\circ}C$ is well within the IOC requirement of $0.2^{\circ}C$.

As a result of these tests, the significant-point selection method has been adopted as the recommended method of compression for the SMODS data base systems. To maintain uniformity, and also to reduce to a minimum the complexity of all future SACLANTCEN digital XBT transfer, only data passing through this system will be allowed entry into the data base.

TABLE 5 'BEST EFFECT' TOTALS FOR EACH METHOD

METHOD	LOWEST MEAN DIFFERENCE	LOWEST MAXIMUM DIFFERENCE	LOWEST ST.DEVIATION OF DIFFERENCE	LOWEST PERCENTAGE REMAINING
1	88	12	6	110
2	29	202	146	112
3	105	8	70	0

TABLE 6 PERCENTAGE OF 'BEST EFFECT' FOR EACH METHOD

METHOD	LOWEST MEAN DIFFERENCE	LOWEST MAXIMUM DIFFERENCE	LOWEST ST.DEVIATION OF DIFFERENCE	LOWEST PERCENTAGE REMAINING
1	39.64	5.41	2.70	49.55
2	13.06	90.99	65.77	50.45
3	47.30	3.60	31.53	0.0

TABLE 7 AVERAGE VALUES OF STATISTICAL TEST PARAMETERS

METHOD	LOWEST MEAN DIFFERENCE	LOWEST MAXIMUM DIFFERENCE	LOWEST ST.DEVIATION OF DIFFERENCE	LOWEST PERCENTAGE REMAINING
1	- 0.0012	0.1966	0.0454	11.959
2	0.0004	0.0735	0.0222	14.780
3	0.0001	0.1955	0.0422	12.875

SUMMARY AND CONCLUSIONS

1. A flexible software comparator has been developed to study the effects of different filter/compression algorithms on digital XBT-profile data. The software will allow other algorithms to be included in the future as they are developed.

2. The comparator has been tried and tested on recently-acquired XBT data and the error limits of the system determined.

3. A recommended standard method of compression has been selected for entry of digital XBT data into the SACLANTCEN Oceanographic Data Base.

4. The comparator will be extended in the near future to look at the effects on digital STD/CTD data for their compression and data-base entry.

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